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A Concept for a Flexible Rehabilitation Tool for sub-Saharan Africa

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Abstract: This concept paper explores a technological building block approach to the development of a flexible rehabilitation tool that may address some of the needs in sub-Saharan Africa. We briefly outline some of the health challenges that lead us to suggest a concept for physical rehabilitation solutions to address many diverse patient groups (e.g. disabled children, cardiac, and stroke patients), to be used in both urban and rural areas, to be easily used in community based rehabilitation (e.g. by community rehabilitation workers), to motivate the users, and to be robust to failure (e.g. power failure) in remote areas. The concept leads to the implementation of modular interactive tiles for rehabilitation, and suggestions for future use in sub-Saharan Africa.

Keywords: Rehabilitation technology, eHealth, playware, modularity, adaptivity.

1. Introduction

In this paper, we describe the concept of technological building blocks for rehabilitation in sub-Saharan Africa, and outline the possibilities for rehabilitation of diverse patient groups in different environments, including rural and remote areas. The concept places emphasis on creating playful interactions with the technological building blocks aiming at motivating patients to perform rehabilitative actions.

Previous studies in Europe have shown the potential of such an approach for activating mentally handicapped children [1, 2], hospitalized children [3], kindergarten children, cardiac patients [4, 5], and stroke patients [5, 6]. These studies were performed in countries with a different infrastructure, larger health spending, and higher availability of health services for its citizens. In sub-Saharan Africa (SSA), a large part of the population lives in remote and rural areas where eHealth solutions will meet numerous challenges. As will be outlined below, some of the most challenging issues in terms of implementing eHealth solutions are the scarce availability of electricity, of technology professionals, and of health personnel. Owing to these issues, both use and maintenance of equipment may radically shorten a lifespan of a given solution.

Due to the flexibility and easy approach to personalization inherent in the modularity, it is our belief that a modular approach as in the technological building block approach may possess the potential of becoming particularly helpful in addressing both the technological challenges and health challenges in such communities. With the high prevalence of disability, stroke and coronary heart cases in SSA countries, it is of high interest to investigate if this kind of an approach would provide an eHealth solution flexible enough to adapt to the needs of patients in such areas. The potential advantage would be that a local community can have one modular solution that any community rehabilitation worker can easily adapt to the individual patient and his/her needs, and with the high prevalence of the mentioned health cases in SSA, the rehabilitation of these individuals would have an important socioeconomic impact.

Initially, we will describe what the health challenges are in rehabilitation of disabled children, stroke, and cardiac patients in sub-Saharan Africa. Thereby, we motivate why we develop a technological building block approach for such rehabilitation, and why this approach is suitable to address these particular rehabilitation challenges in sub-Saharan Africa.

2. Some Health Challenges in SSA

In sub-Saharan Africa there are numerous health challenges and challenges to the rehabilitation of different patient groups. Here we will, in particular, try to outline some of the challenges related to rehabilitation of disabled children, stroke, and cardiac patients in sub-Saharan Africa.

2.1 – Rehabilitation of disabled children

The prevalence of disability is high in low-income countries with up to 20% of the world's poorest people living with a sensory, physical or intellectual disability [7], which affects themselves and their families [8]. Approximately one-third of the world's disabled population are children, and it has been reported that in low income countries, 98% of the children with disabilities do not go to school [7], and only a small fraction receives any rehabilitation. For instance, only approximately 2% to 10% of people with disabilities (including children with disabilities) in Tanzania have access to any type of rehabilitation services [8].

According to Cameron et al. [9], many children with disabilities live in rural or remote areas, which impacts their ability to access the needed services (including hospitals, rehabilitations centers, pharmacies, practitioning nurses and doctors) to a serious extent. Typically the few services available are located in major population centres, and thus children with disabilities living outside these centres have difficulty getting any services. Because of costs, lack of public transportation and lack of knowledge about available services, families from remote and rural areas may never see health care professionals. Even if the services are available, the cost of medical care will be prohibitive to most families [9].

As an example, in Tanzania, patients are lacking both research on and development of the required disability and rehabilitation services [9], which generally seem to not be of high priority [10]. On a more general level, the government health care spending is estimated to be US$4 per capita in urban centres, and it is significantly less in rural areas [11]. One of the known rehabilitation approaches being pursued is community-based rehabilitation (CBR) [12], which often focuses on children and their families. It is described by UN and WHO as:

"[A] strategy within general community development for rehabilitation, equalization of opportunities and social inclusion of all children and adults with disabilities. CBR is implemented through the combined efforts of people with disabilities themselves, their families and communities, and the appropriate health, education, vocational and social services."

Cameron et al. [9] describe how the Comprehensive Community Based Rehabilitation Tanzania (CCBRT) [10] provides a continuum of health care services to children with disabilities and their families in Tanzania with community rehabilitation workers providing integrated home-based services under the supervision of rehabilitation professionals. "Each program has two or three rehabilitation professionals and 10 to 20 community rehabilitation workers. The community rehabilitation workers live and work in the local communities of the children they service. Under the supervision of rehabilitation professionals, they carry out individual rehabilitation plans at no cost to the families." [9]

2.2 – Physical rehabilitation amongst other population groups

Cardiovascular diseases are one of the most prevalent health risks in the world today, in great part due to unhealthy living with unhealthy diet and physical inactivity amongst large parts of the world's population. The World Health Organisation reports that coronary heart disease kills more than 7 million people each year, that strokes kill nearly 6 million, and that most of these deaths are in developing countries [13]. There are estimated 32 million cardiac attacks and strokes annually world-wide [14]. Stroke affects younger people in developing nations compared to developed nations [15]. In Africa, this is possibly 10 to 15 years earlier than in developed countries [16]. The years of potential life lost from stroke are thus large, and have significant socioeconomic consequences in sub-Saharan Africa (SSA). "The high social and economic burden of stroke calls for effective strategies for prevention, treatment, and rehabilitation in SSA." [17].

With stroke patients, long-term blood pressure control is an important therapeutic goal, in view of the high risk of recurrence of stroke and the particularly strong relation with hypertension. Methods for lowering blood pressure include medication, dietary and physical activation/rehabilitation. In their study on stroke prevention, treatment, and rehabilitation in sub-Saharan Africa, Lemogoum et al. [17] describe that "stroke recurrence is high among survivors of a first stroke, of whom 50% will have permanent disability [18]. To reduce the social and economic costs related to long-term care, early identification and management of all cases of stroke, including adequate rehabilitation, is recommended. Care for long-term disabled patients should combine proper medication, physiotherapy, and kinesitherapy, whenever this is feasible and affordable. Since home-based rehabilitation for stroke can have functional outcomes similar to patients who receive inpatient neuro-rehabilitation [19], the former is likely to be less costly and possibly more appropriate in SSA. Education and counseling of a stroke patient's relatives can help maintain family functioning, and in turn leads to improved functional and social outcomes [20]".

Also, most coronary heart disease patients need physical rehabilitation focusing on physical exercise. Though the costs of cardiac rehabilitation may be different (cheaper) than stroke rehabilitation, there is still a great need of actions to be taken for prevention and rehabilitation of cardiac attacks in sub-Saharan Africa, where there is a high prevalence of hypertension which is the major indicator for cardiac attack risks.

For instance, Edwards et al. [21] found that there is a high prevalence of hypertension in rural and urban areas of Tanzania, with low levels of detection, treatment and control. In their study comprising 770 adults in Ilala and 928 adults in Shari, they found that the prevalence of hypertension was around 30%. They conclude that this "demonstrates the need for cost-effective strategies for primary prevention, detection and treatment of hypertension and the growing public health challenge of non-communicable diseases in Sub-Saharan Africa". [21]

3. Technological Building Block Approach

The health challenges outlined above suggest that in sub-Saharan Africa there is a need for physical rehabilitation solutions

- for many diverse patient groups
- which can be used in both urban and rural areas

- which can be easily used in community based rehabilitation, e.g. by community rehabilitation workers
- which motivate the users
- which is robust to failure (e.g. power failure) in remote areas

Due to the relatively low amount of health spendings and of health workers in sub-Saharan Africa compared to high-income countries, the individual health worker will typically need to treat a vast array of health problems compared to the high degree of specialization to single health problems amongst health workers in high-income countries. Therefore, it is of interest to facilitate health workers with eHealth solutions that they can easily use amongst a great variety of patients. Furthermore, it is our belief that a flexible *eHealth* solution based upon technological building blocks may provide the flexibility that facilitates addressing the vast range of rehabilitation needs for disability, heart attack and stroke victims in sub-Saharan Africa, and thereby manifest itself in appropriate physical rehabilitation solutions.

Generally speaking, Technological Building Blocks are units with input-output, processing, and communication power that can attach together to form a whole, which overall behavior emerges from the interaction of these units. Atoms and cells can be viewed as the counterparts of technological building blocks in the biological world. LEGO blocks provide an example of building blocks that allow physical construction, but no construction of functionality. Contrary, with their processing and communication power, the technological building blocks allow for both physical and functional construction. When two technological building blocks are put together, they will start to communicate with each other, and process the incoming information (from communicating neighbor and/or from input) to perform an output (in the form of communication and/or output).

Such technological building blocks can be used to create self-reconfigurable modular robots [22], which autonomously change their physical shape, but here we will focus on how they can be used to create *user-configurable modular interactive systems*. In this case, it is the user who constructs with the technological building blocks to create a physical entity and the functionality of this entity. By making changes to the physical shape of the entity, the user can change the functionality of the entity. This happens simply by attaching or detaching technological building blocks, and moving technological building blocks to different positions. Hence, in such a case, the user is making the physical configuration in a hands-on manner, and the user does not need to do traditional programming to change the functionality of the entity. Therefore, in some cases, it is believed that the building block approach may lead any user to develop solutions in a *simple* and very *flexible* manner. Further, the modularity and distributed processing of the building block approach means that the produced solutions are *robust to failure* of individual building blocks. If one building block fails then the rest will still be working, contrary to most traditional technological solutions with a central processing that makes everything fail if one component fails. Also, since there is no central processing and large infrastructure, but the system is composed of a set of individual building blocks (modules), these may potentially be easily transported around and set up anywhere.

Hence, it seems interesting to investigate such a building block approach in a solution to the physical rehabilitation needs outlined above. In the following, we will describe such a potential solution in which the technological building blocks take the form of modular interactive tiles for playful rehabilitation.

4. Modular Interactive Tiles

The system of modular interactive tiles is a distributed system where the modules can attach to each other to form the overall system. The tiles are designed to be flexible and in a motivating way to provide immediate feedback based on the users' physical gaming interaction, following design principles for modular playware [23].

Figure 1: Modular tiles used for feet or hand interaction

Each modular interactive tile has a quadratic shape measuring 300mm*300mm*33mm – see Fig. 1 and Table 1. It is moulded in polyurethane. Inside, the printed circuit board (PCB) has the electronic components mounted, including an ATmega 1280 as the main processor in each tile. At the center of each of the four sides of the quadratic shape infra-red (IR) signals can be emitted and received (from neighboring tiles). On the back of a tile there are four small magnets. The magnets on the back provide opportunity for a tile to be mounted on a magnetic surface (e.g. wall). Each side of a tile is made as a jigsaw puzzle pattern to provide opportunities for the tiles to attach to each other. The cover is made from transparent satinice.

Table 1: Specification of one kind of technological building block, a modular interactive tile.

	Amount	**Type**
Processor	1	ATmega1280
Sensor	1	FSR
Sensor	1	2-axis accelerometer
Effector	8	RGB colour LEDs
Communication	4	IR transceivers
Communication	1	XBee radio chip
Energy	1	Li-Io Polymer battery
Switch	1	On/Off switch
Connector	4	Jigsaw puzzle
Size	300mm*300mm *33mm	
Weight	1 kg	

A force sensitive resistor (FSR) is mounted as a sensor allowing analogue measurement on the force exerted on the top of the cover. On the PCB, a 2 axis accelerometer (5G) is mounted, e.g. to detect horizontal or vertical placement of the tile. Eight RGB light emitting diodes (LED SMD 1206) are mounted with equal spacing in between each other so they can light up underneath the transparent satinice in a circle.

The modular interactive tiles are individually battery powered and rechargeable. There is a Li-Io polymer battery (rechargeable battery) on top of the PCB. A fully charged modular interactive tile can run continuously for approximately 30 hours and takes 3 hours to recharge – an important long battery life for the utilisation in rural areas in developing countries. The battery has to be charged once in a while, but can then often run for a week if the tiles are used e.g. 3-4 hours a day. The battery status of each of the individual tiles can be seen when switching on each tile and is indicated by white lights. When all eight lights appear the battery is fully charged and when only one white light is lit, the tile needs to be recharged. This is done by turning of the tiles and plugging the intelligent charger into the DC plug next to the on/off switch to recharge each tile.

On the PCB, there are connectors to mount an XBee radio communication add-on PCB, including the MaxStream XBee radio communication chip. Hence, there are two types of tiles, those with a radio communication chip (*master tiles*) and those without (*slave tiles*). The master tile may communicate with the game selector box (an RFID reader that reads RFID game cards) and initiates the games on the built platform. Every platform has to have at least one master tile if communication is needed e.g. to game selector box or a PC.

With these specifications, a system composed of modular interactive tiles is a fully distributed system, where each tile contains processing (ATmega 1280), own energy source (Li-Io polymer battery), sensors (FSR sensor and 2-axis accelerometer), effectors (8 colour LEDs), and communication (IR transceivers, and possibly XBee radio chip). In this respect, each tile is self-contained and can run autonomously. The overall behavior of the system composed of such individual tiles is however a result of the assembly and coordination of all the tiles. The modular interactive tiles can easily be set up on the floor or wall within one minute. The modular interactive tiles can simply attach to each other as a jigsaw puzzle, and there are no wires. The modular interactive tiles can register whether they are placed horizontally or vertically, and by themselves make the software games behave accordingly. Also, the modular interactive tiles can be put together in groups (i.e. tiles islands), and the groups of tiles may communicate with each other wireless (radio). For instance, a game may be running distributed on a group of tiles on the floor and a group of tiles on the wall, demanding the user to interact physically with both the floor and the wall. There are numerous games for both physical and cognitive training.

5. Playful Rehabilitation with Modular Interactive Tiles

Previous studies in developed countries have shown the potential of such modular interactive technology for activating mentally handicapped children [1, 2], hospitalized children [3], kindergarten children, cardiac patients [4, 5], and stroke patients [5, 6]. From these European studies, important insight for the development of playful rehabilitation in sub-Saharan Africa may be found, since the modularity, ease of use, multiple use areas, and robustness, may potentially provide a technology that can be used by *anybody, anywhere, anytime* [24].

In particular, the study of therapeutic use of the modular interactive tiles for rehabilitation of cardiac and stroke patients in Denmark [6] found that therapists use the adaptation property to apply modular interactive tiles in rehabilitation practices that demand *highly individualized training*, and that the therapists therefore may use the interactive modular tiles to provide treatment for a large number of patients who receive hospital, municipality or home care.

Using a qualitative research methodology of the new practice with the modular tiles, the authors [6] found that “therapists are using the modular aspect of the tiles for personalized training of a vast variety of elderly patients modulating exercises and difficulty levels. We also find that in physical games there are individual differences in patient interaction capabilities and styles, and that modularity allows the therapist to adapt exercises to the individual patient's capabilities".

By observing the therapeutic praxis with the modular interactive tiles, the authors enlist numerous different exercises developed and used by the therapist. They conclude that "The list of exercises shows that the tiles are being adjusted to the patients' need when they are part of the rehabilitation praxis. The different parameters such as: the amount of tiles, the arrangement of the tiles, the games and the amount of time are parameters which the physiotherapist can fine-tune and thereby make them to some useful tools for their patients" [6]. Hence, in their daily work, the therapists are taking advantage of the ease with which they can change the tiles set-up, the games and interaction time, in order to adapt the session with the tiles to the individual patient needs. Indeed, apart from observations, also interviews with therapists revealed their *need for rearrangement and adjustment of exercise equipment to the individual patients*.

Another clear finding which is evident from different studies that interview patients is that most patients find exercising on the modular tiles *motivational*, since it is *playful* and it is *fun to compete* against yourself and others [4, 6].

5.1 – Modular tiles for therapy with children

A study of modular interactive tiles use with children with autism indicates that this particular user group is able to interact with the modular robotic tiles, and even if the mentally handicapped children may not make creative performances with the modular interactive tiles, they would however build and interact with the tiles in very individual manners [1, 2]. The particular pilot study gave indication that the technology may be able to *automatically* recognise the individual behaviour, and therefore speculated whether such modular interactive tiles or similar playware can be used as a supplementary tool in the diagnosis process for the children with autism [1, 2].

Also in use in a children's hospital, expression of *self-confidence* and *happiness* after use of modular interactive technology were observed in a physical weak child, and in general the *modularity*, *ease of use* and the *functionality* of the devices was observed to suit into the scenario in the children's hospital [3]. Another important finding from the studies in the children's hospital was that children responded positively to the coloured light feedback, especially when it was produced as an *explicit immediate feedback* on their own actions [3].

It is interesting if similar evaluation by therapists together with adult and child patients will emerge from implementing the modular interactive tiles in rehabilitation practice pilot studies in sub-Saharan Africa. In order to evaluate this, we have initially provided a set of modular interactive tiles to a rehabilitation unit for disabled children in Iringa, Tanzania.

6. A Further Case Study in Tanzania

In spite of the promising results of various separate studies, a lack of studies on broad implementation of the Modular Interactive Tiles in SSA remains. So far, only a very preliminary use test for a limited set of users in a rehabilitation unit and in an orphanage was performed in Tanzania [24]. However, as outlined in this paper, our view is that such a technology would become of best profit for a community when its modularity is spread to a maximal extent. We thus propose a case study to be run simultaneously in Iringa, Tanzania, at the rehabilitation unit, two elementary schools, and a rural hospital. The first will continue employing the tiles for physiotherapy and physical rehabilitation whereas in Illembula, Iringa, the therapy is focused on child patients with cognitive disabilities. At the elementary schools the tiles will be given into children's use to support both cognitive and physical development; this will be done in the forms of both instructed game sessions and free, creative activities.

Essentially, we shall give minimal instruction at each smaller community where the tiles are to be used. The idea is to provide information about results gained within other cultural contexts, and to then build each therapy and educational program with a local professional. It is our belief that such programs will have a greater potential of becoming a part of the everyday life of each community, and hence, over time, of giving more profit to the larger community. This case study is to be continued for six months after which the next steps shall be taken according to an evaluation made within each smaller community.

7. Conclusion

The brief outline of some of the health challenges in sub-Saharan Africa led us to propose the building block concept for creating physical rehabilitation solutions to address many diverse patient groups (e.g. disabled children, cardiac, and stroke patients), to be used in both urban and rural areas, to be easily used in community based rehabilitation (e.g. by community rehabilitation workers), to motivate the users, and to be robust to failure (e.g. power failure) in remote areas. As an example, we developed the modular interactive tiles for rehabilitation, exploiting the modularity to address those issues, and we outlined our future studies in sub-Saharan Africa, which will aim at verifying the feasibility and usability of such a modular approach in rehabilitation.

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